

SCOPE OF WORK

CONSTRUCTED VEGETATIVE TREATMENT CELLS

(WWF Project No. 4.34)

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I. Background

Wetlands have long been recognized as sinks for many pollutants, especially nitrogen and phosphorus. For decades, wetland systems have been used for treating municipal and industrial wastewater, and are often more cost-effective than advanced-wastewater-treatment systems (*Breaux 1995, Mokry et al. 1995, and Green and Upton 1994*). Recent literature reviews presented by *Kruzio (1994), (1995), and Kruzio and White (1996)* showed many experimental studies conducted in the early 1990's suggest that constructed wetlands can treat municipal and industrial wastewater, stormwater (SW) runoff, mine drainage, and landfill leachate.

The available literature on the performance of wastewater-wetland systems is fairly extensive; however, information on the use of natural or constructed wetlands for controlling SW pollution, a newer application, is scarce. Experiences with wastewater wetlands may not apply directly to SW wetlands because the SW wetland systems possess the following characteristics:

- (A) highly variable flow rates that are usually intermittent and seasonal,
- (B) wide ranges (i.e., may vary by two to three orders of magnitude of suspended solids (SS) and chemical composition between storm events (*Baker 1993 and Livingston 1989*),
- (C) site-specific nutrient ratios and concentrations, and
- (D) plant species' performance and removal efficiency is tied to the biota's ability to tolerate the extremely variable conditions (*Livingston 1989 and Silverman 1988*).

The ability of wetlands to reduce SW/combined sewer overflow (CSO)/nonpoint source (NPS) pollutants depends on the plant uptake, soil-sorption capacity, and local hydrologic conditions. In engineering practice, detention time is a critical design factor in a treatment system. Extended detention times allow increased interaction between nutrient and nutrient removal mechanisms, resulting in higher pollutant removal (*Liao and Yu 1997, Liao and Yu 1996, Liao 1996, Yu and Liao 1994, and Yu et al. 1992*). Larger system nutrient capacity yields a longer service life. Because using constructed wetlands for SW treatment is a fairly new application, no general agreements on design criteria or factors have evolved. In the literature, the study of nutrient fate in wetlands with known hydrology is recognized but not detailed. Little comparative data for plant performances under various hydrologic conditions (e.g., detention time versus removal efficiency) for different wetland systems (e.g., free water and subsurface flow systems) is found. There is also little information on the comparative contributions to pollutant removal by settling, adsorption, and plant uptake, or how much pollutant is released from the substratum to the

water column. To address these unknowns and concerns, this research conducts a bench-scale vegetative-treatment -cell study to evaluate pollutant removal efficiency, develop engineering design criteria, and suggest optimal performance, operation and maintenance (O & M) guidance for the SW-wetland systems.

The following is a brief literature review for the project.

Constructed-wetland systems

Interest has steadily increased over the past few years in using constructed wetlands for pollution removal. It is possible to design these systems to accomplish a variety of treatment objectives using influent ranging in quality from raw waste to tertiary effluent (*Jackson et al. 1995, Corbitt and Bowen 1994, EPA 1993, Hammer and Bastian 1989, and Jirgensen 1988*). Constructed wetland's diverse applications and ability to be established almost everywhere, including on lands with limited alternative uses, have resulted in their use both across the country and around the world. For example, in 1992, Reed and Brown (1992) reported that more than 150 constructed wetlands systems in the United States were treating municipal and industrial wastewaters, while a 1994 study estimated that more than one thousand wetland systems had been implemented worldwide (*Wood 1995*). Further information on wetland development, organization, and a searchable wetland database are available through the EPA (*Brown 1994, Brown and Reed 1994, and Brown and Waterman 1994*).

SW-wetland systems

SW-wetland systems are typically constructed with one or more of the following objectives:

- i)** an enhancement of surface drainage;
- ii)** the control of flooding;
- iii)** the control of erosion and sedimentation;
- iv)** the reduction of pollutants; and,
- v)** the creation of aesthetic amenities (e.g., open space and recreation) (*Schueler 1992 and Livingston 1989*).

Hammer (1993) identified the following characteristics of natural- and constructed- SW wetlands: moderate to highly reliable pollutant removal; at least twenty years of longevity; amenability with respect to site installation; high potential for providing wildlife habitat;

marginally higher cost than wet ponds; potential for stream warming; and potential for SW impacts to alter natural wetlands. Hammer (1993) also outlined the need for design improvements for ponds and wetlands. A summary of the present level of knowledge with respect to some of these topics is presented below:

i. SW/Detention Pond Systems

The most effective approach for controlling NPS-related pollutants employs a combination of accepted best management practices (BMPs) for water management and erosion control (e.g., a detention pond), with a constructed-, natural- or restored-wetland system. Detention ponds are a common BMP used for SW control. A typical wetland is shallower (often <10 cm) than a detention pond, producing a smaller runoff containment volume, but introduce biological processes that can compensate for this reduction. For example, emergent wetland plants provide an excellent environment for bacterial growth and algal attachment. Bacterial growth expedites nutrient and organic degradation, while attached algal matter convert nutrients into biomass that eventually settles to the sediment layer. In addition, during summer, increased evapotranspiration results in shallower depths and higher water temperatures that often enhance these biological processes. The diversion of SW flow through aquatic plant systems reduces the runoff flow velocity increasing sedimentation and reducing resuspension.

When placed upstream of a SW-wetland system, detention ponds serve to reduce the kinetic energy associated with runoff, control the hydraulics and flow distribution over the wetlands, and remove relatively coarse-particulate matter.

Downstream of the detention pond, the SW wetlands provide additional storage, reduce flood flows and velocity, reduce downstream erosion and increase sedimentation, and capture and degrade pollutants (*Green and Martin 1996, Guardo et al. 1995, Guardo and Tomsallo 1995, Bingham 1994, Mitsch and Gosselink 1993, Livingston 1988, Athanas 1988, and Hickok 1977*).

ii. Pollutant-Removal Mechanisms in SW Wetlands

Typical pollutants associated with SW include SS, trace metals and metal corrosion products, hydrocarbons and other miscellaneous toxicants, nitrogen and phosphorus, organic matter, and litter and other debris (*Bingham 1994, Schueler 1992, and Linker 1989*). Pollutant removal in SW wetlands occurs primarily through physical processes. These include: sedimentation for various pollutants; chemical precipitation for metals; filtration for debris, organic matter, and solids and their associated pollutants; volatilization for volatile organic carbons and mercury;

biological processes, e.g., nutrient uptake; and, sorption for nitrogen, phosphorus, metals, and viruses (*Baker 1993, Schueler 1992, Whipple 1991, Daukas et al. 1989, Livingston 1989, FHWA 1988, Kadlec 1987, Knight et al. 1987, and Kappel et al. 1985*). For the latter process, the ability of wetlands to successfully sorb nutrients depends on their nutrient capacity and the associated catchment hydrology. Reported ranges of pollutant removals in SW wetlands are:

- (A) sediment, 75-90 %;
- (B) total phosphorus (TP), 55-65 %;
- (C) total nitrogen (TN), 40%;
- (D) 5-day biochemical oxygen demand (BOD₅), 40%; and,
- (E) metals, 0-80 % (*Linker 1989*).

Constructed Wetlands for CSO Control

As with SW wetlands, there is little information on using constructed wetlands to abate CSO pollution. In Cicopee, MA, a pilot-scale constructed wetland study, using both free water (FW, water flow above the substratum surface) and subsurface flow (SF, water flow below the substratum surface) wetlands, showed constructed wetlands were a more cost-effective solution than conventional CSO treatment (*Jubenville et al. 1995*). Another study in Portland, OR, reported on pretreatment requirements, e.g., screening, sedimentation, disinfection, and dechlorination, before CSO discharge into wetlands (*Ochsner et al. 1992, and Nichols 1991*). The Portland study revealed that CSO loadings (both mass and hydraulic) were much lower than those of (secondary effluent) wastewater wetland systems and flow through the constructed wetland successfully reduced the loadings. Hydraulic modeling efforts predicted an optimal detention time of eight weeks.

II. Objectives

The contractor shall accomplish the following to meet the objectives of this project:

1. Determine relative removal efficiencies of SS and their associated pollutants (e.g., total phosphorus and copper) for various detention times, water depths, and pollutant loadings.

2. Submit technical memoranda and complete data sets.

III. Technical Scope

The contractor shall:

1. Develop a Quality Assurance Project Plan (QAPP) for conducting bench-scale experiments to monitor and analyze nutrient and heavy metals dynamics within the system.

The QAPP shall be based on the attached NRMRL Category IV requirements ([Attachment AA](#)) and shall include the detailed procedures and methods for conducting sampling and testing, laboratory bench-scale experimental design, QA/QC procedures to all pollutant parameters, and methods for data analyses and interpretations. The laboratory method shall be comparable with existing *EPA approved* methods. The contractor shall make no reportable measurements without an approved QAPP.

In developing the QAPP, the contractor shall establish and clearly state either
(A) the number of sample replicate analyses, **OR**
(B) the method to be used in determining the number of analyses at the time of analysis.

The contractor shall complete replicate analyses for at least 15% of each sample type in each batch and at least two samples when less than fourteen samples of the same type are analyzed in a given sample batch. The number of replicate analyses shall be set so that the 95% statistical confidence interval on each sample with replicate analyses does not exceed

- (A) 40% of the mean value whenever the mean value is at least twice the detection limit, or
- (B) 100% of the mean value whenever the mean value is less than or equal to twice the detection limit and above the detection limit.

When drafting the QAPP for submission, the contractor is strongly encouraged (not required) to complete a literature review. Such a review will simplify the QAPP submission, review, and approval process.

2. Provide all equipment required for testing.

This work may be done with four treatment cells operated in parallel, or two cells operated in parallel used twice. The submission must clearly identify the configuration and schedule. All cells must be the same size.

There is no geographic preference or requirement for this work. Cells must be housed either

(A) in translucent or transparent structures using ambient, natural light with temperature control or

(B) indoors with grow lights and temperature control.

All cells must assure adequate light for plant health.

The treatment cell must be at least 20-ft long. Treatment cell width may vary but must fall within the established length-to-width ratio guidance.

The substratum shall be washed gravel with diameters no smaller than 2 mm or larger than 50 mm. Substratum depth shall follow established parameters (roughly 40 to 70 cm). Substratum depth in no cell may vary by more than 1 cm from the average of all cells. The contractor must measure and report substratum pore volume for each cell. Inter-cell pore volume shall not vary by more than 15%.

Substratum must be flushed with at least three pore volumes of potable water, drained, and refilled with the test liquid before starting any test.

All plants must be healthy at the start of each test. Plant density will vary with species (cattails and bulrushes at 1 to 2 plants per square meter, reeds at 2 to 6 plants per square meter). Total initial plant mass in cells must not vary by more than 15%.

Influent feed tank(s) must be sufficiently mixed to assure homogeneity and have sufficient volume to complete the full test in all parallel cells without replacement liquid. Influent pump must provide sufficient capacity and capacity range to assure required detention times. Pump control must assure variation in the feed rate will not exceed 10%. Two measurements of the influent or effluent flow rate must be taken each day while the cell is operational. The QAPP must fully explain the flow measurement technique. Flow measurements must be made at least eight hours apart. The pH and temperature of the liquid in the feed tank and the cell effluent must be recorded when measuring the effluent flow rate.

Influent must enter the treatment cell no more than 2-inches from the internal cell bottom. Effluent discharge must be within the free water depth of the treatment cell opposite the influent. The volume to depth conversion must be documented at the depths used for testing.

3. Characterize test system

Treatment cell must be shown to be free of leaks and construction materials shown not to leach any of the monitored parameters into water left standing for 14 days. Materials are considered to leach when the measured concentration in the standing water is above the detection limits in the QAPP after the 14-day holding period.

4. Conduct Testing

The contractor shall perform bench-scale tests outlined in table 1. Table 1 lists the required influent water-quality parameters [based on concentration of TP, either Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), Copper (Cu), Total petroleum hydrocarbons (TPH), and SS], detention time (7 and 14 days, i.e., one theoretical replacement of all liquid water in the cell in the specified period), sampling frequency (7 and 14 days, equal to the detention time), test duration (21 and 42 days, three times the detention time), number of water depths (2, one equal to half the substratum depth and the second equal to the substratum depth), and number of sampling locations within the cell (4, at two depths each). Each test is run with a constant influent particle size distribution. The influent pH shall not vary by more than 0.5 su and temperature shall not vary more than 10% during any single test. Note the **bold red** conditions in table 1 are tests run in duplicate.

Table 1. Water-quality parameters, sampling frequencies, and spiked contaminants in the study.

Shaded blocks represent tests run in duplicate.

	Control		Bulrushes		Cattails		Reeds	
Detention Time (days)	7	14	7	14	7	14	7	14
Sampling Frequency (days)	7	14	7	14	7	14	7	14
Sampling Duration (days)	21	42	21	42	21	42	21	42
TP, COD or TOC, Cu, TPH, and SSØ	H	L	H	L	H	L	H	L
	H	L	H	L	H	L	H	L

Number of sampling locations within each cell	4	4	4	4
Number of water depths to be examined within each cell	2	2	2	2
Particle-size distribution (PSD) (influent and effluent only), Turbidity, pH, Temperature§	Constant in Each Run*	Constant in Each Run*	Constant in Each Run*	Constant in Each Run*

H: High: TP > 5 mg/L, Cu > 2 mg/L, TOC or COD > 100 mg/L, SS > 100 mg/l., HEM > ___ mg/l

L: Low: 1 < TP < 5 mg/L, 0.5 < Cu < 1 mg/L, 50 < TOC or COD < 75 mg/L, 50 < SS < 75 mg/l., ___ < HEM < ___ mg/l

§ Acceptable ranges: temperature 20 to 25C, pH to 8.

* Intra test temperature variation not to exceed 10%, and intra test pH variation not to exceed 0.5 su

Ø If other than four cells in parallel is selected, inter test variation for **High** concentrations shall not exceed 10% and inter test variation for **Low** concentrations shall not exceed 5%

5. Collect samples at the frequencies shown in table 1.

Samples shall be collected from both free water and interstitial water at mid-tank width. The four sampling points shall be at the cell influent and effluent (adjacent to cell walls), one-third cell length, and at two-third cell length. Samples of interstitial water shall be collected midway between the cell bottom and the surface of the substratum. Free water samples shall be collected at mid water depth. All samples collected within the treatment cell must be analyzed without filtration. Beyond samples collected within the treatment cell, samples of the feed tank must be

collected concurrent with samples collected in the treatment cell. These tank samples must be analyzed for all parameters listed in table 1 and filtered TP, COD or TOC, Cu, TPH. For one test with each species, the contractor must concurrently measure evapotranspiration.

6. Analyze collected samples following the QAPP.
7. Perform statistical data analysis on collected data (mean, standard deviation, range) and calculate the removal efficiency for each parameter ((influent concentration - effluent concentration)/ influent concentration).

Removal efficiency shall be reported for both pore water and free water. All analytical results and measurements must be reported.

8. Prepare technical memoranda describing the methods, results of each bench-scale test, conclusions, recommendations, and any problems encountered.

All data shall be presented in a Lotus 123 - compatible spreadsheet. Data must include QA flags as needed. Technical memoranda shall be WordPerfect for windows 6.1 compatible. Any graphics included as part of the technical memorandum shall be part of the document; not separate files. Results shall be E-mailed to the project officer within 2 weeks of test completion. Hard copy shall be sent by US mail within 3 weeks of test completion and shall include copies of all analytical results, copies of any chains of custody, and laboratory log books. Memoranda need not repeat procedures described in earlier submissions.

IV. Deliverables

The contractor shall deliver:

1. Quality Assurance Project Plan
2. Technical memoranda by E-mail copy for each test
3. Hard copy of technical memoranda with attached copies of analytical results, chains of custody, and laboratory log books for each test.

V. Schedule

The total project period will be eighteen months. The contractor shall assure that the following schedule of deliverables is maintained or that revisions to the schedule are approved in writing.

Due Date	Deliverable
One month after award	Final test design with detailed explanations of rationale.
Two months after award	QAPP delivered to Project Officer. Project officer will review and forward to Quality assurance for review and comment. All QA officer comments must be addressed.
One month after QAPP approval	First test (21-day) begins
Two months after QAPP approval	First test technical memorandum
Every 1 or 2 months (based on test duration)	Technical memorandum

VI. Technical Evaluation Criteria

A written proposal fully describing the approach to achieve the objectives of this project shall be prepared, with a detailed schedule for accomplishing the required deliverables. Proposals will be evaluated using the criteria shown below (on the pass/fail basis):

1. Quality of the Researchers

- (A) Demonstrated knowledge of the state-of-the-art of constructed wetlands applications in SW management by the principal researcher(s). At

least three years of applicable storm water research is required. A full CV for the researcher(s), including publications in this area, must be provided.

(B) Demonstrated experience of proposed principal investigators to develop and execute a Quality Assurance Project Plan to accomplish the requirements and the objectives of the SOW.

2. Quality of Proposed Facilities

(A) Quality of facilities and equipments (water quality laboratory, analytical instrument, and computational software and hardware) to perform the requirements of the SOW.

(B) Documented equipment matching the requirements of the SOW.

Attachment AA

QUALITY ASSURANCE FOR CATEGORY IV PROJECTS

[RREL-AA (Apr. 1993)]

A. Quality Assurance Project Plan (QAPP)

This project requires an NRMRL approved QAPP. The QAPP shall be submitted by the awardee to the NRMRL project officer (PO) thirty (30) days prior to the beginning of any measurement, data gathering, or data generation activity. The QAPP shall be submitted as a separate document.

The awardee shall submit five (5) copies of the QAPP to the NRMRL PO in order that the QAPP can be reviewed by the PO and his/her management in concert with the NRMRL QA Manager and/or an authorized representative of the Government. These copies shall be accompanied by a Project Objective Agreement (POA) and a Quality Assurance Project Plan Implementation Agreement with the appropriate signatures. The awardee should also provide any supporting documentation, such as work plans, standard operating procedures, etc.

No measurement, data gathering, or data generation activity may be started without NRMRL's written approval of the QAPP.

Deviations from this will constitute a violation of EPA Order 5360.1.

The QAPP shall contain, in document control format, a thorough discussion of the awardee's and any subcontractor's internal quality assurance and quality control (QA/QC) procedures. It shall also contain provisions for external review of the QA/QC program designed for the project. Guidance on the development of a Category IV QAPP is provided in the RREL Pocket Guide *"Preparing Perfect Project Plans,"* EPA/600/ 9-89/087, Oct.1989. Additional guidance can be found in the document *"Preparation Aids for the Development of Category IV Quality Assurance Project Plans,"* EPA/600/8-91/006, Feb.1991. Both documents can be obtained from the NRMRL QA office. The QAPP shall contain the following key elements as a minimum:

1. Project description, including the intended use of the data.
2. QA objectives for critical measurements (i.e., process and analytical measurements essential to achieving project objectives) and ***the impact of not meeting the QA objectives.***
3. Sampling and analytical procedures.
4. Approach to QA/QC

Following written approval of the QAPP by NRMRL, the awardee and any subcontractor shall implement the approved QAPP. Any substantive changes to the measurement, data gathering, or data generation activity must be documented in a revision to the approved QAPP. Such revisions will require the written approval of the NRMRL PO and concurrence by the QA Manager prior to implementation by the awardee or any subcontractor. (The term *"substantive change"* is defined as *"any change in an activity that may alter the quality of data being generated or gathered."*)

B. Quality Assurance Audits

The awardee and any subcontractor shall anticipate that one or more RREL quality assurance audits may be performed during the project duration. These external quality assurance audits will be performed by an EPA QA Manager or by an authorized representative of the

Government. Selection of the specific areas of focus for audits will be commensurate with the scope and needs of the program. (Note: These external audits are intended to complement, not replace, the good laboratory practice of internal audits performed by the awardee.)

C. Quality Assurance Reporting

Each interim or final report produced as a result of a measurement, data gathering or data generation activity shall include, as an integral section of the project report or as an Appendix, a readily identifiable discussion of the data quality of research results. Interim reports shall include the following items as a minimum:

- Discussions of the quality of data produced in terms of precision, accuracy, completeness, method detection limit, representativeness, and comparability, or semi-quantitative assessments of data quality, as applicable.
- Changes to the QAPP, if any.
- Limitations or constraints on the use of the data, if any.
- Identification of any significant QA/QC problems encountered.
- Resolution (i.e., corrective actions) of significant QA/QC problems.
- Discussions on the QA objectives that were met and those that were not.

The QA section of a project's final report should lend support to the credence of the data as well as the validity of the conclusions. Data quality statements for precision and accuracy shall be included.

The awardee shall comply with EPA's Chapter 5 document *"Calculation of Precision, Bias, and Method Detection Limit for Chemical and Physical Measurements, March 30, 1984"* whenever normally or near normally distributed data are assessed. When data normality cannot be confirmed or assessed, then the awardee shall delineate the specific approach by which the data sets have been assessed.

D. Ethics and Data Integrity

The awardee and any subcontractor shall adhere to an ethics and data integrity code. No person shall participate in:

- the intentional selective reporting of data,
- the intentional reporting of data values that are not the actual values obtained
- the intentional reporting of dates and times of data analyses that are not the actual dates and times of data analyses, and
- the intentional representation of another's work as one's own.

RREL-AA (Apr. 1993)